AAMRL-TR-86-016

THE DERIVATION OF LOW PROFILE AND VARIABLE COCKPIT GEOMETRIES TO ACHIEVE 1ST TO 99TH PERCENTILE ACCOMMODATION (U)

KENNETH W. KENNEDY

HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

MARCH 1986

Approved for public release; distribution unlimited.

HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-86-016

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

AD-A173 454

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AAMRL-TR-86-016	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Harry G. Armstrong Aerospace Medical Research Laboratory 6b. OFFICE SYMBOL (If applicable) AAMRL/HEG	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Wright-Patterson AFB Ohio 45433-6573	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62202F	7184	08	35

11. TITLE (Include Security Classification)
See Reverse

12. PERSONAL AUTHOR(S)
KENNETH W. KENNEDY, Ph.D.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Technical	FROM ____ TO ____	1986 March	26

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Cockpits Cockpits Geometries Accommodation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This study was undertaken to serve three objectives: (1) to derive new cockpit geometries in which the techniques of vertical aircraft ejection seat adjustment move the small pilot toward his/her controls and the large pilot away from them, thus avoiding the incompatibilities associated with adjusting the small pilot up and aft, away from hand controls, and the large pilot down and forward, toward hand controls; (2) to demonstrate the relative ease with which the engineer can accommodate to the 1st to 99th percentile range of male body sizes within the USAF, including reach capability; and (3) to demonstrate appropriate techniques in using the AAMRL Drawing Board Manikins in the derivation of basic geometries of ejection seats and of cockpits. Design requirements are: (1) vertical seat adjustment should be for the purpose of bringing the pilot's eyes to a 15 degree Down Vision Line; and (2) all pilots within the anthropometric design range should be able to avoid thrusting their knees forward of the Ejection Clearance Line by assuming the correct ejection posture, even though they might have adjusted the seat to a considerably different

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION (See reverse) UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL KENNETH W. KENNEDY, Ph.D.	22b. TELEPHONE NUMBER (Include Area Code) (513) 255-8751 22c. OFFICE SYMBOL AAMRL/HEG

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

SECURITY CLASSIFICATION OF THIS PAGE

11. Title:

THE DERIVATION OF LOW PROFILE AND VARIABLE COCKPIT GEOMETRIES TO ACHIEVE 1ST TO 99TH PERCENTILE ACCOMMODATION

19. ABSTRACT (Cont'd)

position than recommended for their body size. Low Profile and Variable Cockpit Geometries are derived in detailed step by step demonstrations.

PREFACE

This effort was conducted under Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) Project 7184, "Man-Machine Integration Technology," Task 718408, "Crew Station Design Techniques and Criteria," and Work Unit 71840835, "Engineering Anthropometry for Systems and Subsystems Design."

This paper was presented as part of the Symposium of the 26th meeting of the Air Standardization Coordinating Committee (ASCC), Working Party 61, "Aerospace Medical and Life Support Systems," 5 November 1985. at the RAF Institute of Aviation Medicine, Farnborough, Hants, England. It also appears in the Report of that meeting, Volume IV, "Symposium Proceedings."

OBJECTIVES

The study reported here was undertaken to serve three objectives:

1. To derive new aircraft cockpit geometries in which the techniques of vertical ejection seat adjustment move the small pilot toward his/her controls and the large pilot away from them, thus avoiding the incompatibilities associated with adjusting the small pilot up and aft, away from hand controls, and the large pilot down and forward, toward hand controls;

2. To demonstrate the relative ease with which the designer can depart from the United States Air Force tradition of accommodating to the 5th to 95th anthropometric percentile range and to accommodate, instead, to the 1st to 99th percentile, including reach capability; and

3. To demonstrate appropriate techniques of using the AAMRL Two-Dimensional Drawing Board Manikins in the derivation of basic geometries of two diverse ejection seats and of selected aspects of cockpits.

Design requirements to be met by the cockpit geometries are as follows.

1. Vertical seat motion is for the purpose of adjusting the pilot so that his eyes can be located on the 15 degree Down Vision Line, over the nose of the aircraft, rather than on the traditional Horizontal Vision Line (Plane). It is felt that optimum vision both into and out of the cockpit can best be achieved by adjusting to the Down Vision Line.

2. All pilots within the anthropometric design range should be able to avoid thrusting their knees forward of the Ejection Clearance Line by assuming the correct ejection posture, even though they might have adjusted the seat to a considerably different position than recommended, considering their body size.

The 1st to 99th percentile ranges of body sizes to be accommodated are listed below. This is a typical example of the manner in which anthropometric percentile range accommodation is best applied to design. The 1st to 99th percentile accommodation range is applied only to the key dimension(s).

Eye Height, Sitting	1st to 99th Percentile
Thumb-Tip Reach	1st Percentile to Top of Range
Buttock-Knee Length	Bottom of Range to 99th Percentile
Buttock-Popliteal Length	1st Percentile to Top of Range
Knee Height, Sitting	1st Percentile to Top of Range
Popliteal Height, Sitting	1st Percentile to Top of Range
Bideltoid Breadth	Bottom of Range to 99th Percentile
Hip Breadth, Sitting	Bottom of Range to 99th Percentile

First and 99th percentile limits are specified only for Eye Height, Sitting, the one listed dimension whose extremes both must be considered. This dimension plays a decisive role in determining vertical seat adjustment range and, therefore, the total depth of the cockpit. Contrary to the apparent belief in many airframe companies and military agencies, Sitting Height is not the most critical body dimension in cockpit layout, since it is taken into account by the military services' convention in calling for a 9- to 13-inch arc originating at the Design Eye Position and to which the underside of a canopy or overhead fuselage must be tangent.

All layouts were developed using the AAMRL Two-Dimensional Drawing Board Manikins.* Since these design aids are currently available only in 5th, 50th and 95th percentile sizes, minor adjustments had to be made on the drawing board to represent the 1st to 99th percentile accommodation requirements. In the text that follows, references will frequently be made to 1st and 99th percentile torsos as though actual manikins of these sizes were used. This is a convenience to avoid the otherwise cumbersome necessity to refer frequently to the adjustments made to derive 1st and 99th percentile values.

THE LOW PROFILE COCKPIT GEOMETRY

The impetus for developing the Low Profile Geometry can be traced to conversations with members of the original cadre established at Wright-Patterson Air Force Base, Ohio, to initiate studies leading to what is now known as the Advanced Tactical Fighter (ATF). Drawing on these conversations, as well as from lessons learned in the AAMRL High Acceleration Cockpit (HAC) experience and from work done by the author, a basic low profile geometry was developed. It was driven by the following design requirements in addition to those listed in Objectives.

1. It was specified by the ATF cadre that the frontal area of the fuselage of a low profile aircraft be significantly less than that typical of aircraft currently in the inventory. Expressed in terms important to the geometry of the ejection seat, the frontal area through the cockpit at Seat Reference Point (SRP) should be approximately 80 percent of that of the F-16A.

* See Bibliography for references regarding the AAMRL Drawing Board Manikins.

2. A seated posture must be produced that would passively resist submarining during ejection, but would not result in the pilot's knees encroaching on the 15 degree Down Vision Line.

A reduction to 80 percent of the vertical frontal area through the cockpit of the F-16A results in a vertical distance of approximately 37 inches from the full-down SRP to the underside of the canopy.* This compares to 41.5 inches for the F-16A. Allowing a 9-inch clearance from the eyes to the underside of the canopy reduces to 28 inches the vertical space within which to accommodate to the 99th percentile for Eye Height, Sitting (34.8 inches). A rather supine angle is obviated.

As body attitude proceeds more and more toward supination, the head is more likely to require frequent if not continuous support. The minimum back angle at which this occurs is unknown, but it appears to be at about 45 degrees.** If we also expect the pilot to be able to see comfortably forward both into and out of the cockpit, the head must be supported in an upright attitude, essentially as it assumes in the unsupported situation. To determine an appropriate head orientation for a straight ahead gaze, a sample of 30 individuals were examined. It was found that, when looking straight ahead, the angle between Tragion (essentially at the upper margin of the external auditory meatus - ear hole) and the inferior margin of the orbit (bony eye socket) averaged +11 degrees.

The more supine the back angle becomes, the more the head must be rotated forward in order to maintain a natural head orientation. As this occurs, the greater is the likelihood that the chin and respiratory gear will come into contact with the chest. It is felt, therefore, that at rather supine back angles, the upper back and head should be elevated from the plane of the lower back to avoid the possibility of this interference. Although elevating the upper back and head will increase the heart valve eye distance and likely lessen somewhat the pilots' tolerance to +Gz accelerations, the discomfort and possible compromise of equipment that may otherwise occur would be unacceptable. Accommodation to the 99th percentile torso within the vertical space allowed, such that these requirements are met, requires a lower back angle of approximately 55 degrees aft of vertical and an upper back/head rest angle of approximately 10 degrees aft of vertical. The distance from SRP to the beginning of the upper back/head rest was found to be 19 1/8 inches.

* The vertical dimension of the cockpit has traditionally been expressed in terms of the distance between the Neutral Seat Reference Point (NSRP) and the underside of the canopy. I have departed from this convention for the purpose of including full vertical seat travel in this value.

** The angle of support for the upper back is critical. If the upper back is supported at an angle less than 45 degrees aft, it may be that continuous head rest is not needed.

With the 99th percentile torso still on the drawing board, the minimum uppermost limit for the top of the head rest was marked.

These first steps in developing the Low Profile Cockpit Geometry are illustrated in Figure 1.

First to 99th percentile reach accommodation can be achieved merely by locating hand operated controls at the 1st percentile reach distance. All personnel with longer arms are automatically accommodated. Using this procedure in the aircraft cockpit, however, is inappropriate and can lead to an array of hand operated controls and display surfaces that are too close to many operators and can cause the crewstation to be too confining for large pilots.

In the cockpit, accommodation to the 1st to 99th percentile range for reach capability can be achieved in another far more appropriate fashion. By taking advantage of the fact that the smaller pilot will move the seat upward and the larger pilot downward to reach the Down Vision Line, we need only to accommodate to the minimum practical reach capability compatible with the 99th percentile torso in the full-down seat adjustment, and to the minimum reach compatible with the 1st percentile torso in the full-up seat adjustment. The minimum practical Thumb-Tip Reach to be found associated with the 99th percentile torso was

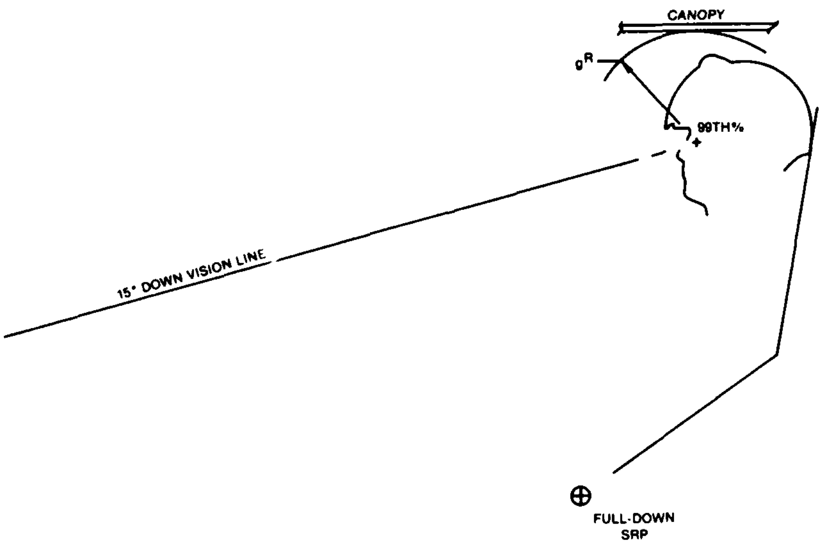

FIGURE 1. The Low Profile Cockpit Geometry - Initial Determinations. A 55 degree lower back angle and 10 degree upper back-head rest and the Over-the-Nose Vision Line have been established. Since the 99th percentile eye position will be the highest along the Over-the-Nose Vision Line, the clearance radius to the underside of the canopy can also be indicated.

found to be 30.7 inches, or 29th percentile.* With the 99th percentile torso in the full-down seat adjustment, the 29th percentile reach point is located directly forward. This reference point will be used to achieve 1st and 99th percentile reach equivalence.

It was certain at this point that the 1st percentile torso with the maximum likely leg (75th percentile) in the full-up seat adjustment would be the body proportions likely to cause the knees to rise the highest in the cockpit and, therefore, most likely to interfere with the 15 degree Down-Vision Line. For this reason, I ignored the height to which the knees of the 99th percentile leg on the 99th percentile torso might rise in the cockpit with the seat full down.

It was not yet known which of the torso/leg/seat adjustment combinations would cause the knees to protrude farthest forward and, therefore, be determinant in the placement of the Ejection Clearance Line. However, to preserve this information for possible future use, the forward protrusion of the knees of the 99th percentile torso and leg was marked.

Since it was not yet possible to determine the compressed surface of the seat cushion, it was also not possible to indicate the placement of the rudder pedals. For the time being, then, the 99th percentile torso and its limbs were set aside and attention was turned to the uppermost seat adjustment.

The seat in its uppermost adjustment must be positioned such that 1st percentile Eye Height, Sitting is on the Down Vision Line and the 1st percentile Thumb-Tip Reach point at the same distance forward as that for the 99th percentile torso/29th percentile arm combination in the full down seat adjustment. Preserving this relationship by using an appropriate body support system will yield 1st and 99th percentile reach capability equivalence.

The 1st percentile torso with 1st percentile upper limb was positioned on the drawing onto the 55 degree back - 10 degree upper back/head rest.

* Minimum likely reach is defined as the value for Thumb-Tip Reach calculated from Eye Height, Sitting, using the appropriate regression equation, less 1.64 X the Standard Error of the Estimate. [88.3 cm (99th percentile Eye Height Sitting) X 0.516 (Slope) + 38.54 cm (Constant)] - [1.64 X 3.66 (Standard Error of the Estimate)] = 78.1 cm (30.7 inches) which is 29th percentile USAF Thumb-Tip Reach. Applying this procedure to estimate the maximum likely leg length (Buttock-Knee Length) associated with the 1st percentile torso results in a 75th percentile lower limb. Other combinations, i.e., maximum likely upper limb/1st percentile torso and minimum likely leg/99th percentile torso were also available, but not pertinent.

To establish the angle of the seat, one that would provide passive resistance to submarining during ejection as well as not violate the Down Vision Line, the 75th percentile leg was attached to the 1st percentile torso, and rotated upward until the knee was 1 inch below the Down Vision Line. A line tangent to the underside of the thigh was drawn to portray the angle of the compressed seat cushion. Since this is the longest practical Buttock-Knee Length associated with the 1st percentile torso and, since the seat is full up, it also represents the highest point to which any pilot's knees are likely to be found.

The SRP of the seat in its uppermost adjustment turned out to be 3 3/4 inches above that in the lowermost adjustment and along a line 5 1/2 degrees aft of vertical. The distance from SRP to the lower edge of the upper back-head rest was found to be 15 3/4 inches.

These additional steps in the derivation of the Low Profile Seat Geometry are included in Figure 2.

To determine seat length and full forward rudder in the aftmost rudder carriage adjustment, the 1st percentile leg was used. The length of the seat compatible with the manikin's Buttock-Popliteal Length was marked and found to be 17.5 inches. An arc was drawn from the center of rotation at the knee to the heel

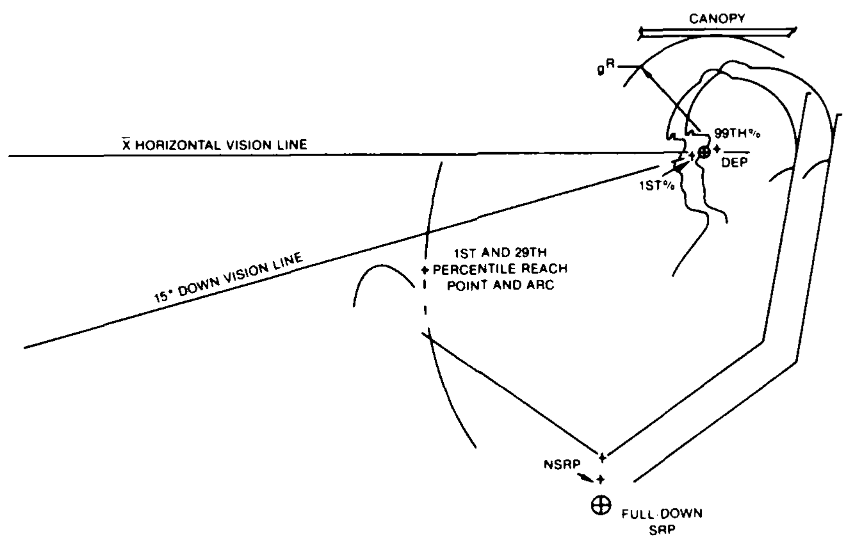

FIGURE 2. The Low Profile Cockpit Geometry - Intermediate Determinations. The uppermost seat position has been determined. With the placement of the 1st percentile eye on the Down Vision Line, the range of eye positions are known. The Design Eye Position (DEP) can, therefore, be determined as well as the Horizontal Vision Line. The maximum height to which the knee can be expected to rise in the cockpit is also shown.

catch to represent full forward rudder in the full aft adjustment. With this geometry it is understood that full right (left) rudder will likely cause the left (right) knee of the 1st percentile torso/29th percentile leg combination to be elevated above the Down Vision Line. Because of canopy interference, it is anticipated that the largest pilots cannot raise the seat high enough to elevate their knees to a yet higher level.

The angle and length of the compressed seat cushion was reproduced onto the full down SRP and the 99th percentile torso with the 99th percentile leg was laid on the drawing such that the lower surface of the thigh coincided with the seat surface. The most forward protrusion of the knee was marked for determination of the Ejection Clearance Line. Also, as with the 1st percentile torso/75th percentile leg, an arc was drawn in the rudder pedal area, equal to the distance from the center of rotation at the knee to the heel catch. Using this arc, full forward rudder in the full forward carriage adjustment can be determined.

For illustrative purposes, full forward rudder pedal positions for full forward and full aft carriage adjustments were located at the intersections of the leg arcs and a line at -4 degrees from the hip joint center of the 99th percentile torso. Such a location should provide for easy pedal actuation. Obviously, several alternative locations and excursions are possible.

The completed Low Profile Geometry appears in Figure 3. The upright headrest would be the posture of choice for normal flying. Included is a head rest position which is in the same plane as the lower back and which could be used with the expectation of very high +Gz loadings. A third head rest position, set at 30 degrees from vertical, could be included and would be used on ejection. It would assume an ejection angle set at 30 degrees or less aft. An Ejection Clearance Line was drawn which allows for 2 inches clearance forward of the 99th percentile Buttock-Knee Length.

THE VARIABLE COCKPIT GEOMETRY

Unfortunately, ejection seat design technology has been such that we have been required to accept what is, in the Human Factors sense, an unacceptable characteristic of ejection seats: namely, the adjustment of the smaller pilot up and aft, away from his controls, and the larger pilot down and forward, toward his controls. At first glance, it might appear that all we need do to solve this incongruity is to adjust pilots along a ramp, the small pilot up and forward and the large pilot down and aft. However, since pilots are known to adjust the seat to positions _they_ choose, and not necessarily to positions the designer chooses for them, they can be counted on frequently to adjust themselves higher in the cockpit than recommended by the designer. Using the ramp concept would increase the probability that their knees would be thrust forward beyond the Ejection Clearance Line. To avoid this problem using the ramp concept would require that the Ejection Clearance Line be far enough further forward so that all pilots will clear, regardless of their seat position. Since the forward control and display panels must be located forward beyond the Ejection Clearance Line, the ramp technique would force the former to be out of reach for all but the very largest pilots. Also, an up-and-forward ramp would enlarge and displace forward the pilot-seat center of mass as well as increase the weight of the seat. Technology, therefore, has required that the pilot be adjusted along angles within a few degrees of the back plane and ejection rails.

One of the purposes of this study is to equate 1st and 99th percentile reach capability. In doing so, it is obvious that the upper torso and shoulders of the smaller pilot will have to be forward of those of the large pilot. Because the geometries must be compatible with the cockpit of the F-16A, it was decided to use that seat geometry in the full down seat position for the pilots with the longest torsos, or, in other words, 99th percentile Eye Height, Sitting. Such an individual with the smallest practical reach capability would represent least reach with the seat full-down.

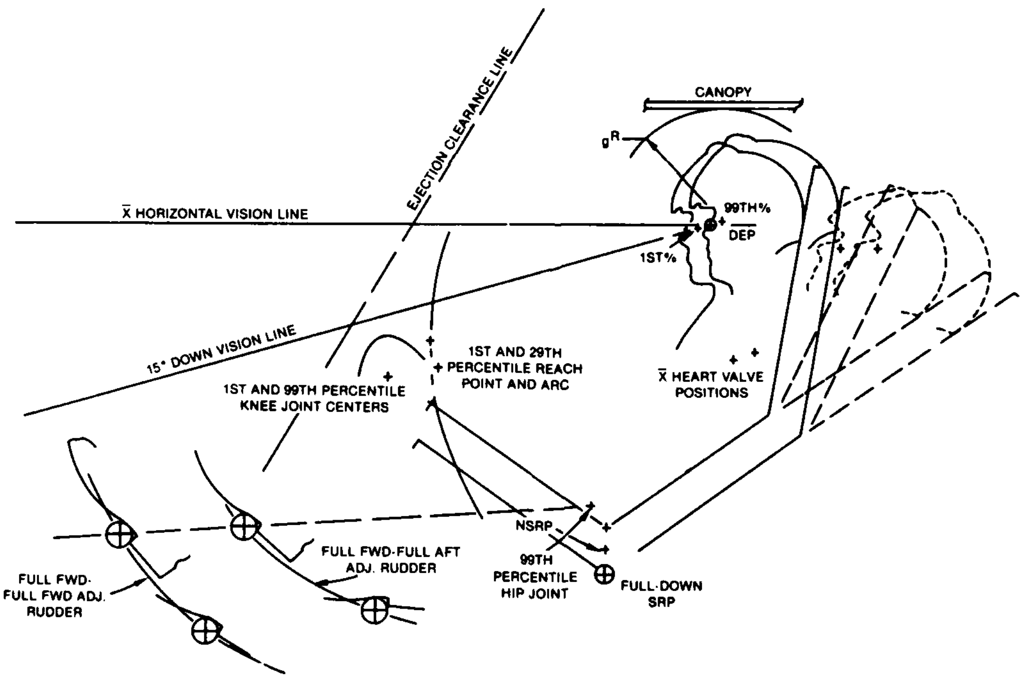

FIGURE 3. The Low Profile Cockpit Geometry - Final Determinations. The lowermost seat position is indicated, as is the full-down Seat Reference Point (SRP) and the traditional Neutral Seat Reference Point (NSRP). With the position of the maximum forward knee known, the Ejection Clearance Line can be determined. Rudder pedal positions and a head rest for possible use in anticipation of the onset of high +Gz are also shown.

To establish the minimum likely reach when the seat is full down, the 99th percentile torso was equipped with the 29th percentile upper limb and 99th percentile lower limb and installed into the full-down seat. To simulate a comfortable seated flying position, the upper torso was balanced over the abdomen and hips and the head and neck were adjusted to permit comfortable vision into and out of the cockpit: The eye-ear line was set at +11 degrees. The eye point was marked and a 9-inch radius drawn above to assure that adequate clearance was maintained from the uppermost eye position to the underside of the canopy. A line was drawn through the eye point at -15 degrees to represent the Down Vision Line. To indicate minimum arm reach, the upper limb was extended forward and horizontal and adjusted to simulate reach with the shoulder moderately extended. The Thumb-Tip Reach point was marked.

The head was rotated aft and the height of the top of the head rest was marked.

The thigh was adjusted appropriately in the seat and the forward curvature of the knee was marked to record its maximum forward extension. To simulate full forward leg thrust and, therefore, full forward rudder at full forward carriage adjustment, the popliteal region of the leg was placed into contact with the most forward, upper surface of the seat. An arc was drawn in the rudder pedal area, originating at the knee joint, and equal to the distance to the center of the heel catch. This, along with a similar arc for the 1st percentile leg on the 1st percentile torso, would be used to establish full forward rudder and range of carriage adjustment.

These steps in the derivation of the Variable Cockpit Geometry are illustrated in Figure 4.

Once the full-down seat geometry was laid out, it was necessary to establish the geometry for the full-up seat. This is most conveniently done using the 1st percentile torso equipped initially with the 1st percentile arm and leg.

The first step is to overlay the Thumb-Tip Reach point on the hand of the 1st percentile upper limb onto that of the 29th percentile arm previously determined. The arm is then straightened out horizontally in the aft direction. The shoulder joint is adjusted and the head and neck were oriented as before for optimum vision. The whole manikin was then raised vertically until the eye was on the Down Vision Line. With these two reference points maintained, the lower two segments of the torso were rotated into an appropriate position to produce a SRP near the SRP for the full-down geometry. A straightedge, held against the lower back, helped maintain a straight back plane. The thigh was rotated upward into a seated position to produce a 95 - 100 degree open angle between the seat and seat back.

There are several geometries possible for the uppermost seat position. In making a final selection, it was necessary to consider the following factors.

1. The transition between full-down and full-up seat adjustments should be essentially a rotational motion originating as close to the knees as possible so that, when underway in the upward direction, the knees are not thrust forward.

2. As with the full-down geometry, that of the full-up position should be one that is familiar to and accepted by the USAF flying community.

3. The transition from full-down to full-up should be made with the least possible motion.

To accommodate to the latter requirement without seriously jeopardizing reach equivalence, the manikin was moved upward along the 15 degree Down Vision Line to a point 3 inches from the 99th percentile eye point. By compromising in this fashion, the 1st percentile reach point receded aft approximately 1 inch from that for 99th percentile and head motion while raising the seat would be reduced.

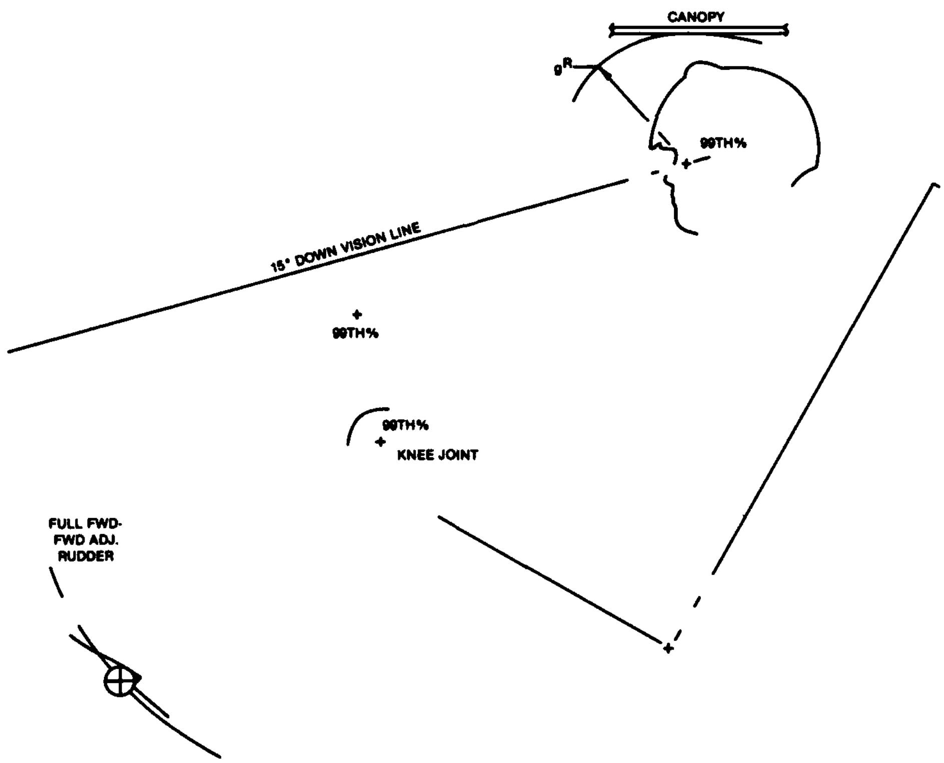

FIGURE 4. The Variable Cockpit Geometry - Initial Determinations. The geometry of the F-16A seat is used for the full down position. The 99th percentile eye and knee positions, Down Vision Line, canopy clearance, and full forward rudder can be located using the 99th percentile drawing board manikin.

One combination of back and seat angles that fits adequately all of these criteria is 18 degrees aft and +11 degrees, respectively. The 18 degree back angle is quite close to the familiar 15 degree back angle found in the F-15 and other aircraft. A back angle set at 20 degrees or greater would require less angular back motion, but, since the shoulder acts as a more or less stationary hinge point in determining acceptable back angles, a steeper back angle would result in the seat pan, and therefore the knees, being thrust forward during upward travel. This would require that the Ejection Clearance Line be located considerably farther forward, and beyond which few pilots could reach. The 18 degree back and +11 degree seat angles yielded an open angle of 97 degrees, well within the accepted range for an "upright" seat.

Once the final geometry for the full-up seat position was selected, the forward edge of the seat cushion was marked at 18.5 inches from SRP to correspond to the Buttock-Popliteal Length of the larger lower limb.

The SRP for the full-up seat was found to be 5.25 inches above the full down SRP, along a vector at 24.5 degrees aft of vertical. The NSRP, of course, would be found midway along this line. The entire system would rotate, with a small amount of sliding, around a point 2.5 inches aft from the forward edge of the seat.

The shank of the 1st percentile lower limb was then rotated downward into the rudder pedal area and an arc was drawn, originating at the knee joint center and equal in length to the distance to the heel catch. This arc, then, represents full forward rudder position in the full aft adjustment.

The 1st percentile leg was replaced by the 75th percentile leg and the forwardmost extension of the knee noted. It was found not to extend farther forward than the 99th percentile knee. The Ejection Clearance Line, then, was set at 34.5 degrees aft of vertical to correspond to the F-16A and 2 inches forward from the 99th percentile knee. So as to assure that the largest pilot could not thrust his knees forward beyond the Ejection Clearance Line, the 99th percentile torso was equipped with the 99th percentile leg and installed into the full-up seat. Even though it turned out to be an unrealistic position, since the head extended above the canopy, the knees were not thrust beyond the Ejection Clearance Line.

For the purpose of illustration, the full forward throw for the rudder pedals in the full forward and aft adjustments was set at the intersections of the leg arcs and a line set at -4 degrees from the 99th percentile hip joint center in the full-down seat.

The final Variable Seat Geometry is illustrated in Figure 5.

DISCUSSION

The Low Profile Seat Geometry is illustrated, with dimensional information included, in Figure 6. Tolerance to relatively high levels of +Gz loads can be expected using such a geometry especially when taking advantage of the full-aft head rest. The basic geometry is not altered as the seat is adjusted upward, even though the length of the lower back segment shortens to 15 3/4 inches from 19 1/8 inches.

Because the seat pan is tipped up to a relatively high angle (35 degrees) and upward seat motion is along an aft angle (5 1/2 degrees) and only 3 3/4 inches in length, knee thrust forward is minimized. It is adequate, however, to force the Ejection Clearance Line beyond the reach capability of all subjects. For this reason no hand operated controls can be located forward. This turns out to be of little consequence since nearly all available space forward that might be used for control placement has been eliminated by the extent to which the knees are elevated. With

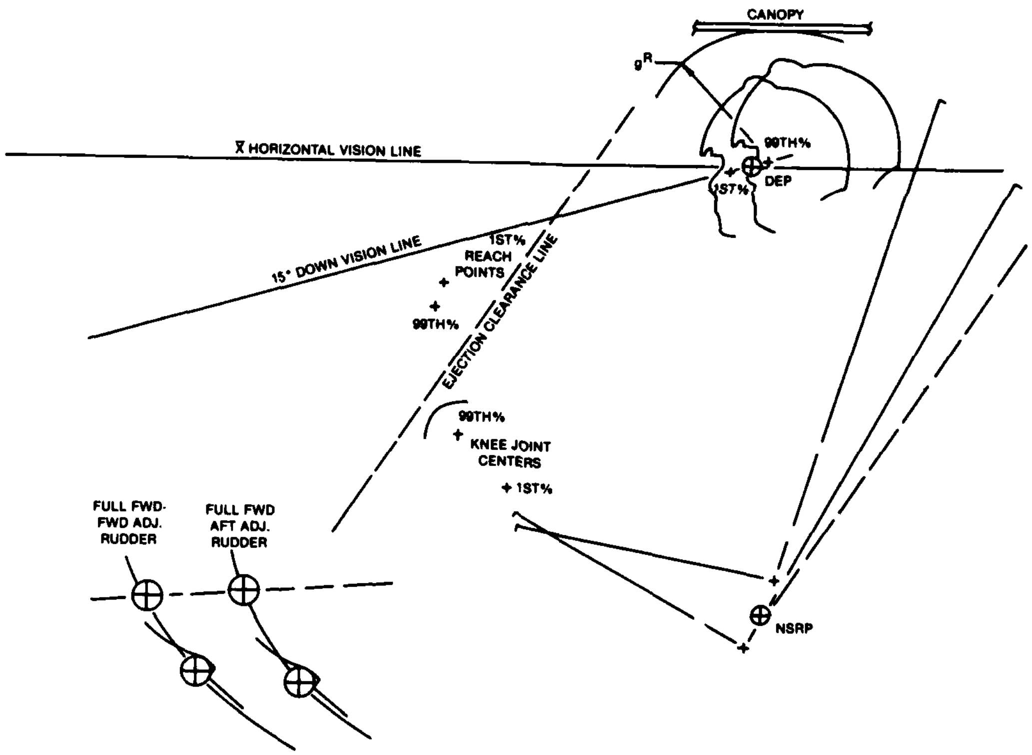

FIGURE 5. The Variable Cockpit Geometry - Final Determinations. The full-up seat geometry has been determined with a rotation point just behind the knees. With the location of the 1st percentile eye position on the Down Vision Line the Design Eye Position (DEP) and the Horizontal Vision Line can be determined.

rudder actuation, some pilots will frequently see one or the other of his knees above the Down Vision Line. Reach in the forward direction is somewhat aided by the fact that the upper back and head are supported at a lesser angle than the lower back and the shoulders are forced somewhat forward. However, all ejection seats that support the body in a near-supine attitude and maintain that attitude during ejection will tend to force the Ejection Clearance Line beyond reach.

Since the 99th percentile knee is now known to be that which projects farthest forward, the Ejection Clearance Line can be set. The full forward rudder in the aft most adjustment is also shown.

As additional information, average heart valve positions were approximated and reductions in the blood column between heart and brain was estimated for the upright and aft head positions. The upright head position for the 50th percentile torso results in a 12 percent reduction when compared to that expected in the F-16A, in which the average heart valve/eye distance is estimated to be 32 cm. When the head and shoulders are full aft in the proposed high +Gz head rest position, the reduction is approximately 33 percent. If we can presume a 15 degree angle of attack, these reductions increase to approximately 14 and 53 percent, respectively.

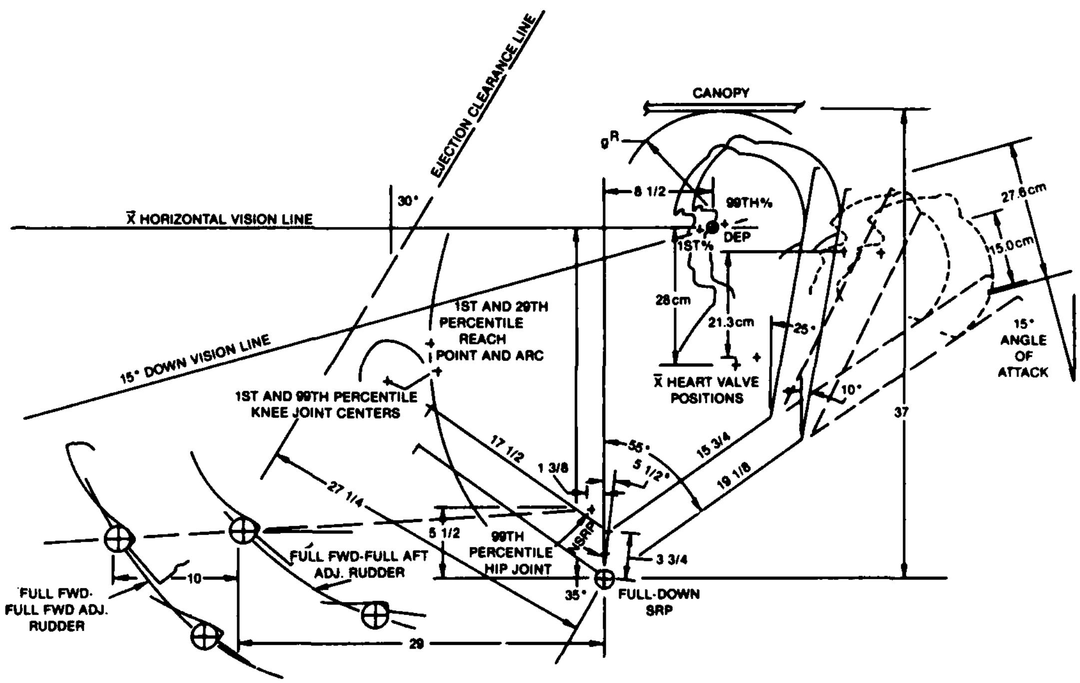

FIGURE 6. The Low Profile Cockpit Geometry. Dimensional information and approximate positions of heart valves for the upright and reclined head rest positions are illustrated.

The completed Variable Cockpit Geometry is illustrated in Figure 7. It can be expected to offer essentially the same tolerance to +Gz accelerations as that offered by aircraft such as the F-15 and F-16. When in the full-down seat adjustment, the pilot can expect the same tolerance as found in the F-16. When full-up, the back angle has changed from 30 degrees aft to 18 degrees, which is slightly greater than that of the F-15.

It has been observed that, with the onset of ejection from the full-up seat position, the seat could rotate into the full-down geometry, using the transition to dampen the effect of the very high acceleration rate on the smaller pilot. The rapid rotation of the man and seat, even though only 12 degrees, will obviously need to be carefully considered. If it is found that such a rapid transition cannot be tolerated, an ejection angle closer to 18 degrees could be considered. Insofar as the effect the resultant 18 (or so) degree Ejection Clearance Line would have on forward control placement, the 1st and 99th percentile reach points appear far enough forward that the reach requirement could still be met.

The knees would move fore and aft very little when adjusting from full-down to full-up seat position. This feature has the

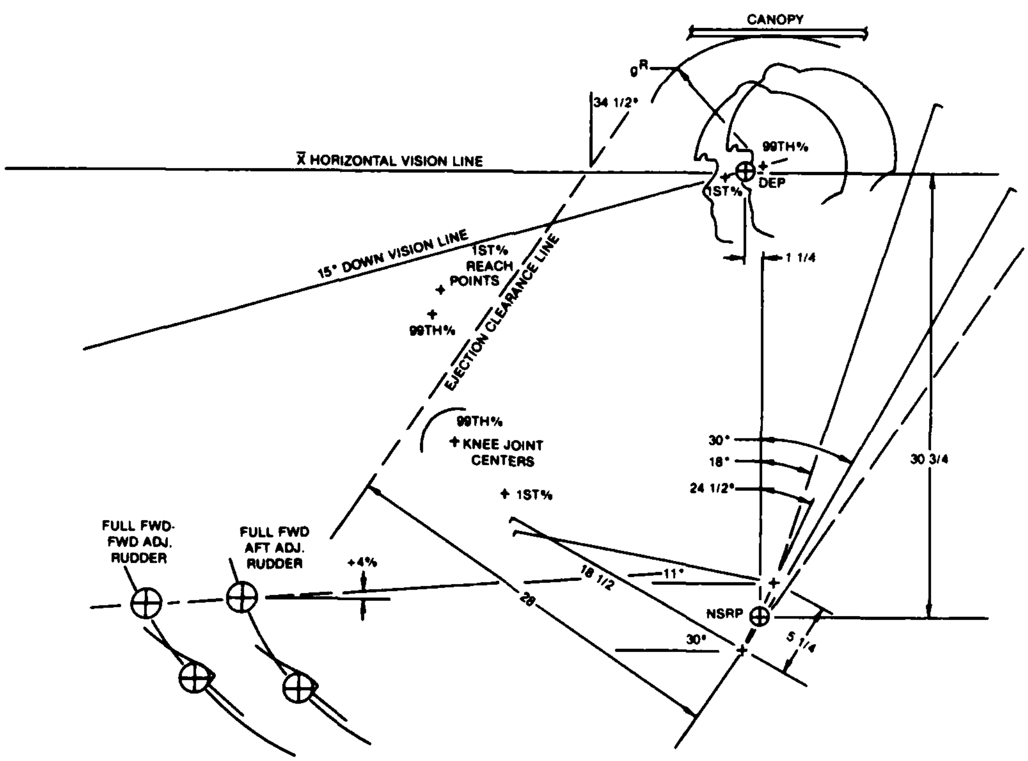

FIGURE 7. The Variable Cockpit Geometry. Appropriate labelling and dimensional information have been added.

advantage of requiring less rudder carriage adjustment than current cockpit geometries. It is estimated that such a seat geometry installed into the cockpit of the F-16A would allow the full range of pilots to use only the forward half of the current carriage adjustment.

Adjusting the pilot's eyes to the 15 degree Down Vision Line resulted in an unexpected advantage. Because the upper torso and head are rotated forward as the seat is adjusted upward, the eye of the smaller pilot also is found to be further forward. Since adjustment is made to the Down Vision Line, this means that the eyes of the smallest pilot will also be approximately 1 inch lower than those of the largest pilot. This requirement makes it possible to accommodate the 1st to 99th percentile range with only 5.25 inches of vertical seat travel.

MOCKUPS

A mockup of the Low Profile Seat Geometry is illustrated in Figure 8. It is completely motorized so that the geometry,

FIGURE 8. The Low Profile Cockpit Geometry Mockup - Large Subject Accommodation. The seat is full-down, rudders full forward, and the eyes are on the 15 degree Down Vision Line.

including the length of the back, changes as the seat is adjusted vertically. The subject measures 35.6 inches for Eye Height, Sitting. That is above the USAF 99th percentile. His Thumb-Tip Reach is 34.6 inches, or 96th percentile.

To facilitate access to the Down Vision Line, a cross hair sight was mounted at the upper edge of the display panel and trained on a target straight ahead but at -15 degrees. In an attempt to reach the Down Vision Line, the subject has adjusted to the full-down position. Because of the his great Sitting Height, however, he was not able to acces the Down Vision Line as conveniently as desired for optimum demonstration. Because the seat is full-down and because his arm reach is so near the 99th percentile, arm reach equivalence can still be demonstrated.

The accommodation of the smaller pilot is illustrated in Figure 9. This subject measures 30.0 inches for Eye Height, Sitting, or 5th percentile, and 30.4 inches for Thumb-Tip Reach, or 21st percentile.

FIGURE 9. The Low Profile Cockpit Geometry Mockup - Small Subject Accommodation. The seat is almost full-up, rudder full aft, and the eyes are on the 15 degree Down Vision Line.

The Variable Geometry Seat mockup is illustrated in Figure 10. It is motorized so that the geometry changes automatically and gradually during the transition from the full-down to full-up. *The large subject has adjusted the seat to the full down* position to achieve 15 degrees vision over the nose. Therefore, the seat back is 30 degrees aft and the seat is 30 degrees above horizontal.

Note his reach capability forward.

The accommodation of the small subject is illustrated in Figure 11. Note that reach capability forward is essentially the same as that of the large subject.

For the purpose of illustrating reach equivalence, the smaller subject is a bit too large in terms of his reach capability and the large subject too small. Considering the direction of their discrepancies, it may turn out that the seat geometry in the uppermost position should be a bit farther forward than described. This, however, can be determined for certain only after running more subjects.

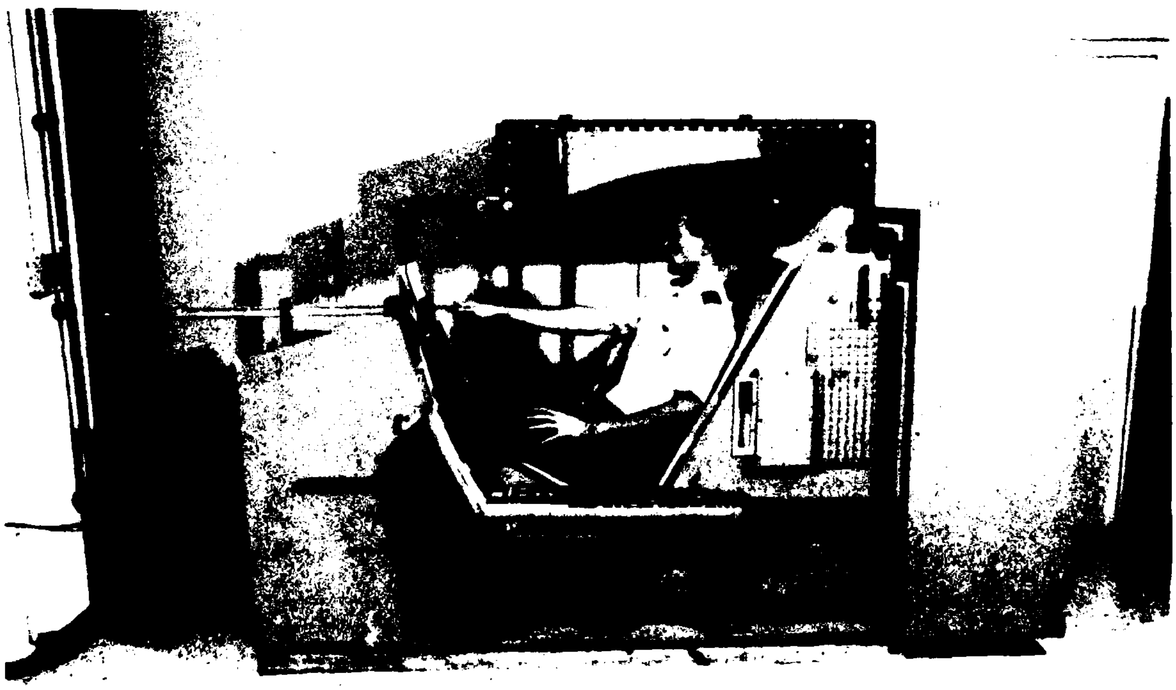

FIGURE 10. The Variable Geometry Cockpit Mockup - Large Subject Accommodation. The seat is full-down, back angle 30 degrees, rudders full forward. Note this subject's reach capability.

To cover the possibility that the 18 degree back angle in the full-up position may not be the most appropriate, the final full-up back angle can be set at any angle between 16 and 20 degrees. This is done by changing the position of the upper end of the surface along which the seat rolls in its upward travel. Changing the final back angle in the full-up position also alters the full-up seat angle.

The seat geometry in the full-down position is never altered.

It was decided early on that I would want to be able to compare reach capability and eye positions using the variable geometry with these entities in the F-16A. For that reason the mockup was designed to simulate both geometries. By moving a catch-slide behind the seat when the seat is full down, upward motion of the SRP can be aft along 24.5 degrees, as previously described, or at 34.5 degrees aft as in the F-16A. The 30 degree back and +30 degree seat angles are not altered during the F-16A adjustment.

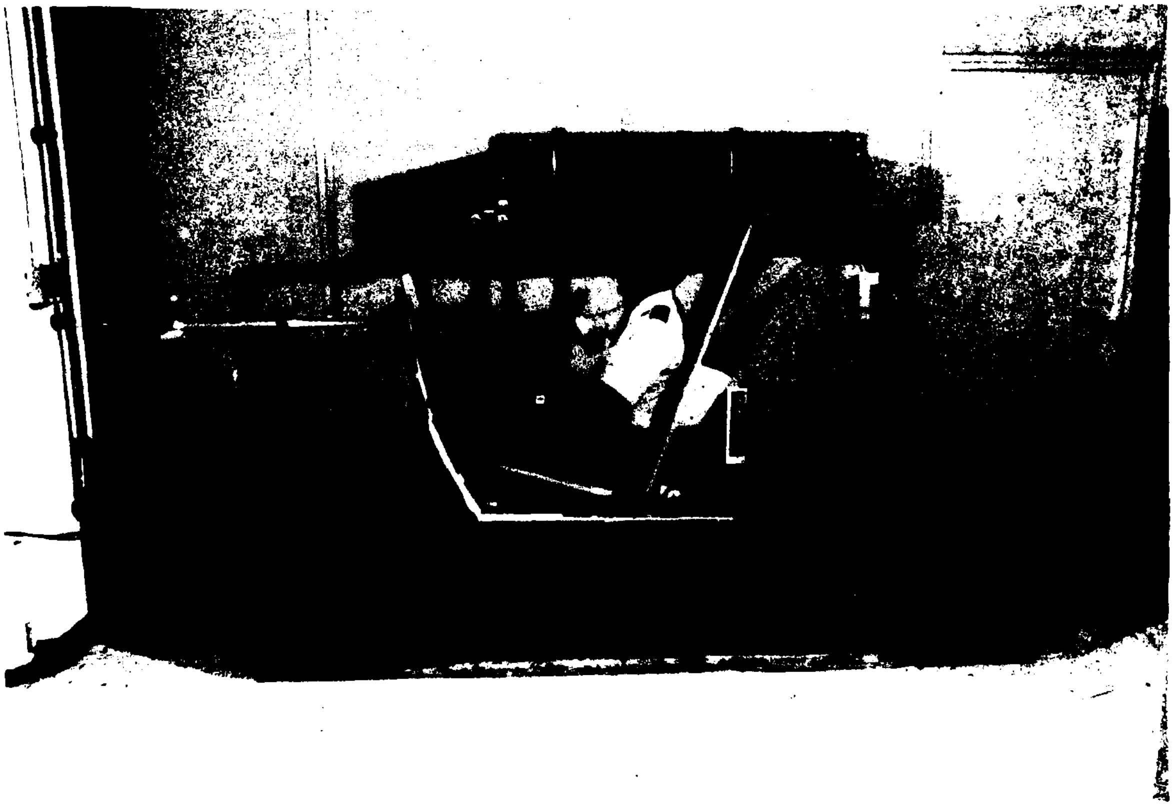

FIGURE 11. The Variable Cockpit Geometry Mockup - Small Subject Accommodation. The seat is nearly full-up, the back angle is approximately 20 degrees. Note that this subject's reach forward is essentially equivalent to that of the large subject in Figure 10.

Seat and back angular and vertical motion and eye position can all be tracked by observing appropriate scales mounted on the side of the mockup. Eye position can be tracked using a transparent grid which can be rotated into position at the side of the subject's head. A realistic replica of the overhead segment of the canopy can be rolled into position once the subject is installed into the seat.

BIBLIOGRAPHY

Air Standardization Coordinating Committee, "Aircrew Anthropometric Scale Models for Engineering Design," ASCC Advisory Publication 61/36, 11 September 1984.

Kennedy, K.W., "New USAF Drawing Board Manikins for Crew Station Design," Aerospace Medical Association Scientific Meeting, San Francisco Hilton Hotel, San Francisco, California, April 1975.

Kennedy, K.W., "Estimating Relaxed Tolerance to +Gz Accelerations through the Use of Drawing Board Manikins," Aerospace Medical Association, Bal Harbour, Florida, May 1976.

Kennedy, K.W., "Workspace Evaluation and Design: USAF Drawing Board Manikins and the Development of Cockpit Geometry Design Guides," NATO Symposium on Anthropometry and Biomechanics: Theory and Application, 7-11 July 1980, Queens College, Cambridge, England and in _Anthropometry and Biomechanics: Theory and Application_, NATO Conference Series III, Vol. 16, Edited by R. Easterby, K.H.E. Kroemer and D.B. Chaffin, Plenum Press, New York and London, 1982.

Kennedy, K.W., "Low Profile and Variable Cockpit Geometries to Achieve 1st to 99th Percentile Accommodation," Symposium of the 26th Meeting of the Air Standardization Coordinating Committee, RAF Institute of Aviation Medicine, Farnborough, England, November, 1985 and in Volume IV, "Symposium Proceedings," Report of the 26th Meeting of ASCC Working Party 61.

☆ U.S. GOVERNMENT PRINTING OFFICE 1986 - 646-006/40201